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ANTI-SKID AIRCRAFT BRAKING SYSTEMS,(U)

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ANTI-SKID AIRCRAFT BRAKING SYSTEMS

by

Jerzy Pruss

FOREIGN TECHNOLOGY DIVISION

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Anti-skid Aircraft Braking Systems

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Abstract : Operation principles of aircraft braking systems and analysis of forces acting on a wheel during braking : classification of contemporary anti-skid systems.

Landing Wheel Braking

Aircraft braking system enables the brake steering of individual landing gear wheels by a change of frictional force momentum in brake frictional elements. Construction of the landing gear is such that it enables:

- simultaneous braking of the main landing gear
- differential braking of both main landing gear wheels
- braking of main landing gear wheels while parked

Some of the aircraft have an ability of all wheels braking, ie. including the front wheel. Modern braking systems have another common characteristic, which is the ability of automatic brake unblocking in case of skid between the tire tread and runway surfaces.. The size of braking momentum, depending on a quality of antiskid system, is adjusted automatically in such a manner as to utilize to the greatest degree the adhesion between the wheel and runway surface for each phase of motion.

The landing wheel braking systems utilize most often the hydraulic method for heavy aircraft and the pneumatic method in the light aircraft. The hydraulic-pneumatic systems are also used. The wheel braking systems assure approximately proportional dependence between the input signal X, which may be for example, the force exerted by pilot on the brake pedals, and

a pressure P generated in the system. This dependence, shown as an example in Fig. 1., should satisfy certain conditions, which assure the proper and reliable brake action. These requirements are defined as follows:

- Time between the appearance of maximum step input signal and the appearance of maximum braking momentum should be within 1 - 1.5 sec.;
- $x_1 \leq 0.25\ x_{max}$, where: x_1 - magnitude of the input signal near the starting point for which there is no detectable output yet,
  x_{max} - maximum input signal;
- $\Delta x_{max} \leq 0.1\ x_{max}$, where: Δx - width of the possible insensitivity regions for input signal;
- $\Delta p_{max} \leq 0.15\ p_{max}$, where: Δp_{max} - maximum uncontrolled change in the output signal. p_{max} - maximum output signal;
- $\pm\Delta' p_{max} \leq 0.1\ p_{max}$, where: $\pm\Delta' p_{max}$ - the largest deviation from the maximum required output signal;
- $x_{2max} \leq 0.15\ x_{max}$ where: x_{2max} - maximum allowed insensitivity for the input signal in point $p = p_{max}$.

The forces acting on a wheel

During the braking action (Fig. 2.) on a turning wheel, the following forces and momenta are active (not considering the force of inertia and assuming no side forces):

- force from the load acting on a wheel (P),
- adhesion force (F_p),
- ground reaction force (R),
- brake friction force momentum (M_t),
- adhesion force momentum (M_p),

The adhesion force momentum is defined as friction force momentum about the wheel axis between the tire tread and the runway surface. It may be described by the following expression:

$$M_p = \mu P (r - \delta_u) = P_p \cdot r_d$$

where: μ - adhesion coefficient of the tire tread and the surface, r - geometrical wheel radius, δ_u - tire distortion due to the load, r_d - dynamic wheel radius $(r_d \cong r - \delta_u)$.

The adhesion coefficient μ is a variable quantity and depends on a wheel velocity, tire pressure, runway condition, tire tread condition and on skid amount between tire and surface. Studies of the adhesion coefficient for various forward velocities, different surface conditions and tire pressures, indicate that its value is always larger for the rotating wheel than for the completely braked (full skid).

The adhesion coefficient usually decreases with the wheel forward velocity.

As it was mentioned, the adhesion coefficient depends on the degree of skidding. The degree of skidding is determined in per cent by a relation

$$W = \frac{n_0 - n}{n_0} \cdot 100 = \frac{\omega_0 - \omega}{\omega_0} \cdot 100\%$$

where: n_o, ω_o - number of rotations and angular velocity of the unbraked wheel, n, ω - number of rotations and angular velocity of braked wheel.

Dependence of the adhesion coefficient and the degree of skidding for various forward velocities is shown in Fig. 3. (1). From the graphs it follows that the adhesion coefficient maximum for a dry cement surface varies from 0.4 to 0.6 and for rather narrow regime of 10 to 20% of the degree of skidding.

The wheel motion equation is given as

$$I_k \cdot \frac{d\omega}{d_t} = M_p - M_t = -\Delta M$$

where: I_k - wheel momentum of inertia about its axis.

Depending on the ratio of the brake frictional momentum M_t to the adhesion momentum M_p the following types of wheel motion take place:

(1) $M_p > M_t$: in this case the wheel turns with certain angular deceleration and with certain skid.

(2) $M_p = M_t$: this case may be described as a state of unstable equilibrium; the wheel turns with certain skid, but a small decrease in adhesion force momentum or small increase in brake frictional force of any origin, causes sudden change in the type of wheel motion.

(3) $M_p < M_t$: in this case the wheel is completely blocked and skids on the surface without turning.

From the considered forces and other causes acting on a wheel during its motion it follows that to obtain the shortest braking distance the following relation is true during the entire aircraft landing time:

$$M_{t\,max} = M_{p\,max} = \mu_{max} \cdot P(r - \delta_u)$$

The braking systems in modern aircraft are designed in such a manner as to approach the braking process as close as possible to the optimal (that is, to the above given relation). During landing, the wheels roll on the surface of varying conditions (e.g. from dry concrete, to wet concrete, ice or snow). Adhesion coefficient varies rapidly, and so changes the adhesion momentum. The aircraft braking system should rapidly adjust the friction momentum M_t to the changing adhesion momentum. At large system delays, the aircraft wheels rolling from a dry concrete to an icy concrete will skid, which will considerably lengthen the landing distance.

The adhesion momentum M_p depends also on a loading force P acting on wheels. During landing, the aircraft weight is distributed on the main wheels and the front wheel (in a case of three wheel landing gear). Ignoring the initial influence of the aerodynamic forces on wheel reaction, the pressure on the main wheel and the front wheel changes depending on aircraft

deceleration. Increase of the aircraft deceleration causes increase of front wheel loading and decrease in loading of main wheels (fig. 4.) The aircraft braking system should take this fact into account by adjusting the friction momentum to changing adhesion momentum, depending on a change in aircraft deceleration.

The automatic braking systems, while getting close to taking into account all the factors influencing the change of adhesion momentum and possibility of accurate satisfaction of the condition given by the above formula, becomes more extensive, complex and costly.

Classification of aircraft anti-skid systems

The systems based on the angular wheel deceleration (negative acceleration) ε

General diagram of such a system is given in Fig. 5.

The anti-skid systems based on wheel angular deceleration measurement operate on a principle of cyclic pressure reduction in braking system. Cyclic operation results from a proper choice of antiskid braking system characteristic frequency. The operation effectiveness depends on frequency and on pressure amplitude.

Higher frequency and smaller amplitude cause higher value of the adhesion coefficient. Presently used systems operate at frequencies of 5 to 10 Hz and amplitude equal to 20-40% of the maximum braking momentum. Systems based on a wheel angular deceleration measurement may be classified as follows:

- Systems containing the inertial-electrical sensor of wheel deceleration. The electrical signal from the sensor steers the electrohydraulic distributor in the braking system, which either cuts off or delivers oil to the wheel brakes. The Soviet aircraft TU-104, IL-18, AN-10, amongst others, are equipped with this type of system.
- Systems with inertial systems of direct action. The automatic

system contains the inertial sensor, which in direct mechanical manner steers the valve cutting off the flow of braking fluid. This type of braking system is common in Western aircraft. The most known design is the MAXARET system by Dunlop. Another firm, MESSIER/HISPANO offers similar systems under the name Ministop. Systems of this type are found, amongst others, in the equipment of the VC-10 and BAC111 aircraft.

- The system containing the velocity sensor in the form of a d.o. generator with the differentiating circuit. The electrical output signal, which is a function of wheel deceleration, steers the hydroelectric distributor which increases or decreases the brake system pressure. The firm MESSIER/HISPANO manufactures this type of system under the name of Minimodulator used among others on the French aircraft Mirage III and Mirage IV.

The first two systems have some disadvantages, in which one may include:

- Small operating effectiveness: eg. average adhesion coefficient on a dry concrete is 0.25 as compared with maximum value of 0.7 to 0.8 for low velocities and 0.35 to 0.40 for high velocities;

- "stiffness of the operation due to the sensor setting for constant deceleration for various conditions of tire tread and surface interaction;

- heavy load on the undercarriage resulting from the fluctuating nature of the operation;

- short service life (about 1000 landings) as a result of this fluctuating nature of the operation.

The third system has certain advantages as compared with the previous ones, due to the use of relatively simple velocity sensors - namely the tachometric generators instead of acceleration sensors. Moreover, this arrangement enables the introduction of correction signals to the system. In order to increase the safety during aircraft braking, especially in the first moments after touchdown, when the wheels do not have sufficient adhesion to the ground, the two-signal systems are used. The first signal

is obtained from the deceleration sensor, and the system works as described above. The second signal, from the wheel angular velocity sensor, operates when the deceleration sensor signal disappears.

An example of such a system is given in Fig.6. Its operation is as follows: after turning on the switch 3, the contact E is closed, and contacts A, G and W open; distributor 9 is in such a position that the air from reductor 1 may flow to the brake. When the landing gear is lowered the contact G closes. Before touchdown the pressing of the reductor 1 lever causes air inflow into the system and closing of contact 2. The electric circuit closes now through contact B and the distributor 9 cuts off air flow to the brake. After touchdown, when the main wheel achieves the right angular velocity, contact B opens and the distributor opens air flow to the brake. Wheel brakes. After the front wheel speeds up, contact W closes and contact G opens due to the shock absorber load. At the appearance of wheel skid the deceleration sensor acts and the contact A closes, switching the distributor into position cutting off the air flow to the brake. If the aircraft leaves the surface or goes into a long skid, after about two seconds the accelerator sensor signal disappears; contact A opens and the wheel starts to brake up to certain revolutions, at which contact B closes and the wheel is released. The two signal system operates at velocities up to 50 to 70 Km/h. At velocities below 50km/h contact W opens, and contact B closes and the system works as the single signal system.

The systems based on the measurement of the angular velocity difference $\Delta\omega$ between braked and not braked wheel.

Block diagram of such a system is shown in Fig. 7. The measured quantity of the interaction state between runway surface and the main landing wheel, is the angular velocity difference $\Delta\omega$ between not braked (eg. front) and braked wheel.

The system input signal can be the pilot's force acting on the reduction valve lever setting the pressure in the braking system. Next the working factor acts on the brakes through the electrohydraulic distributor.

In another system, the pilot through the electric transmitter, steers the electrohydraulic amplifier, which sets the pressure valve acting on a brake. Signals from the angular velocity sensors of braked and non-braked wheel are sent to the system computing their difference $\Delta\omega$, and then to the circuit adding this signal to the pilot's signal.

The advantage of a system with angular velocity measurement as compared with a system based on a measurement of deceleration ε is, that in this case there is no signal disappearance when the aircraft bounces off the landing surface or during a long skid on ice.

Systems based on measurement of skid W

Block diagram of a system is shown in Fig. 8.

The antiskid system with a skid measurement is an extension of a system based on a measurement of angular velocity difference $\Delta\omega$. It contains all the components of that system in addition to the circuit computing the skid value W.

Such a system shows greater effectiveness than the one with measurement of $\Delta\omega$, since the introduction of a skid signal allows the wheel braking with a momentum that takes into account the runway conditions. The braking distance of the aircraft equipped with a system measuring skid W is shorter than the aircraft with measurement of wheel angular velocity difference $\Delta\omega$.

Self Adjusting systems

Block diagram of a self adjusting system is shown in Fig. 9.

The principle of operation of such a system is based on searching for

the optimal adhesion coefficient regime between the tire tread and the surface depending on the skid magnitude (Fig 3). The system reacts to the sign of differential $\frac{\partial\mu}{\partial\omega}$, depending on which, the braking system pressure increases or decreases. The firm MESSIER/HISPANO realized such a self adjusting system under the name SPAD. It was used, among others, on the aircraft Airbus and Mirage G8.

Self adjusting systems are characterized by great complexity and difficulties in determining the value $\frac{\partial\mu}{\partial\omega}$. The adhesion coefficient sensor may be realized for example, on a principle of braking moment measurement.

Self adjusting systems are based on a proportional relay action, and operate in a certain region around the point $\mu = \mu_{max}$.

Summarizing this short description of aircraft anitskid braking systems, one may conclude that starting with a system measuring the deceleration ε , and ending with a self adjusting system, the degree of complexity increases, and so is the cost, but at the same time the effectiveness of the system increases, which may be confirmed from the results of the studies as shown in Figs 10 and 11 (2). The graphs are based on the measurements of the separate systems in the test stations. The graph in Fig. 10 shows the aircraft deceleration as a function of landing velocity, and the graph in Fig. 11 shows the braking distance as a function of landing velocity.

Using these results one may evaluate the effectiveness of each system. If one assumes that the shortest aircraft braking distance at the maximum adhesion coefficient is 100%, so for the described systems it increases as follows:

self-adjusting relay based	105%
self-adjusting proportional	110%
measurement of skid ω	125%

measurement of angular velocity	140%
measurement of deceleration	175%
blocked wheels (full skid)	215%

Bibliography

1. I.I. Zveryev, S.S. Kokonin, Proyektirovaniye aviatsyonnykh Koles i tormozhnykh sistiem (" Design of the aircraft wheels and braking systems") Mashinostroyeniye, Moskva 1973

2. A.M. Matvieyenko, Y.N. Pieyko, Razchot i ispitaniya gidravlicheskikh sistiem letatielnykh apparatov ("Calculation of aircraft hydraulic systems") Mashinostroyeniye, Moskva 1974

3. T. Wrzesiński, Hamowanie pojazdow samochodowych ("Automobile braking systems") Wydawnictwo Min. Komunikacji, Warszawa, 1973

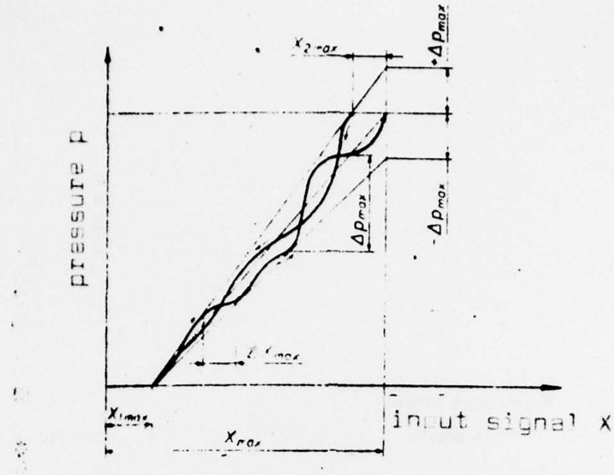

Fig. 1. Dependence of the braking system pressure as a function of input signal.

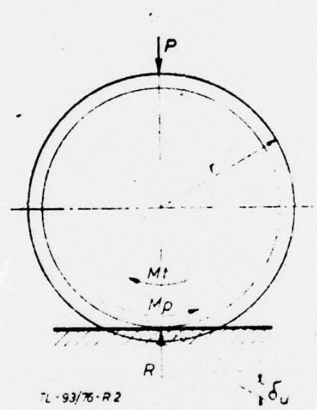

Fig. 2. Forces acting on a rotating wheel

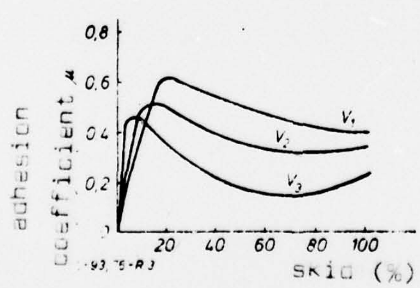

Fig. 3. Dependence of a adhesion coefficient vs. skid for different forward velocities. $V_1 \angle V_2 \angle V_3$

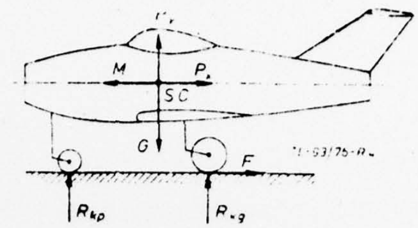

Fig. 4. Forces acting on an aircraft during braking at landing:

(P_y - aerodynamic force, P_x - aerodynamic drag, M - inertia,

G - weight, F - adhesion force between tire and surface,

R_{kp}, R_{kq} - ground reactions, S.C. - center of gravity

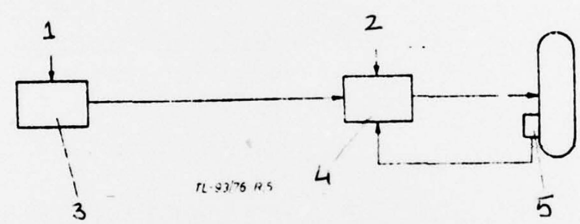

Fig. 5. Diagram of the antiskid system with a measurement of wheel angular deceleration 8.

1. Pilot's signal, 2. Auxiliary signals, 3. reduction valve,
4. electrohydraulic distributor, 5. deceleration sensor

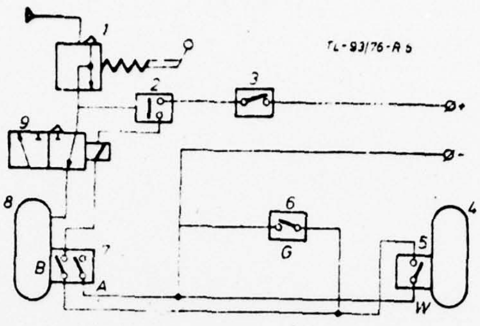

Fig. 6. Diagram of the two-signal antiskid system: 1-reduction valve, 2-pressure cut-off, 3-on switch, 4-non braked wheel, 5-rpm sensor, 6-front wheel switch, 7-deceleration and rpm sensor, 8-braked wheel, 9-distributor

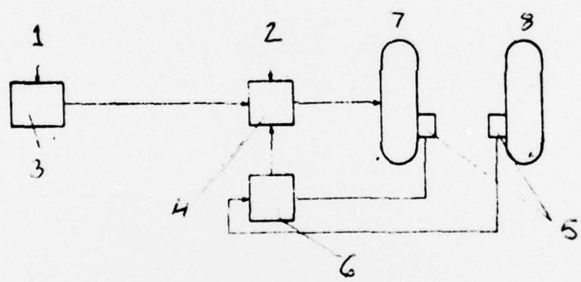

Fig. 7. Diagram of the antiskid system with the measurement of angular velocity difference .

1. Pilot's signal, 2. auxiliary signals, 3.reduction valve, 4. electro-hydraulic distributor, 5. revolutions sensors, 6. block computing the velocity difference, 7. braked wheel, 8. non-braked wheel

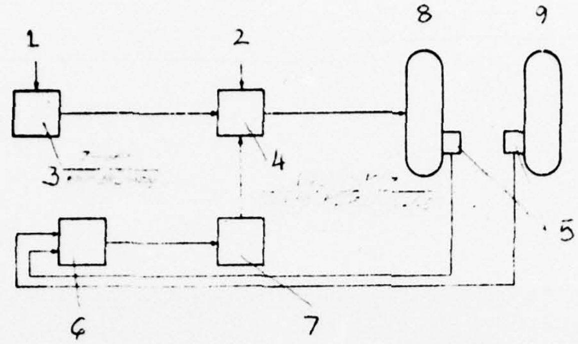

Fig. 8. Diagram of the antiskid system with the measurement of skid W

1. Pilot's signal, 2. auxiliary signals, 3. reduction valve, 4. electro-hydraulic distributor, 5. velocity sensors, 6. block computing the velocity difference, 7. block computing the skid, 8. braked wheel, 9. non-braked wheel

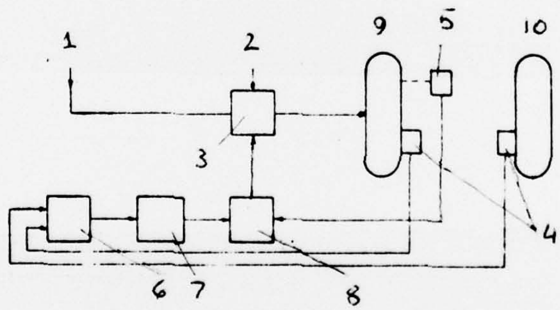

Fig. 9. Diagram of the self adjusting antiskid system

1. Pilot's signal, 2. auxiliary signals, 3. electrohydraulic amplifier, 4. velocity sensors, 5. adhesion coefficient sensor, 6. block calculating the velocity difference $\Delta\omega$, 7. block calculating the skid W, 8. block calculating the $\frac{\partial\mu}{\partial\psi}$, 9. braked wheel, 10. non-braked wheel

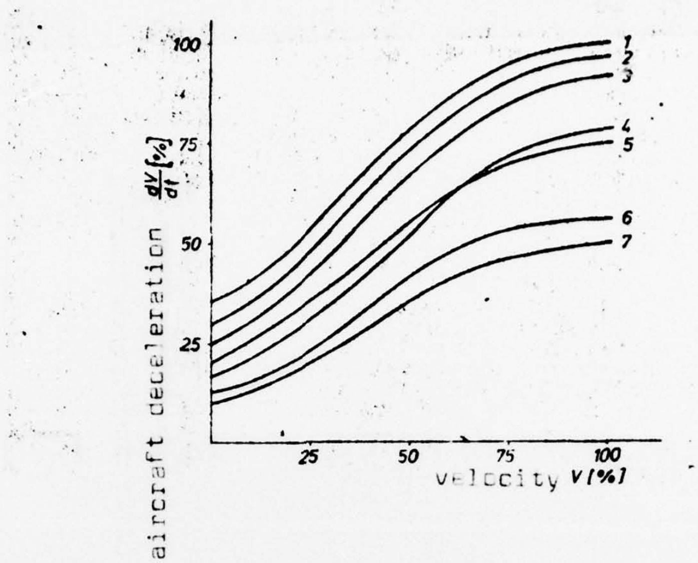

Fig. 10. Dependence of the aircraft deceleration vs. velocity for different antiskid systems: 1- motion at μ_{max}, 2-self adjusting proportional, 3-self adjusting relay, 4- $\Delta\omega$, 5-W, 6-s, 7-wheels blocked.

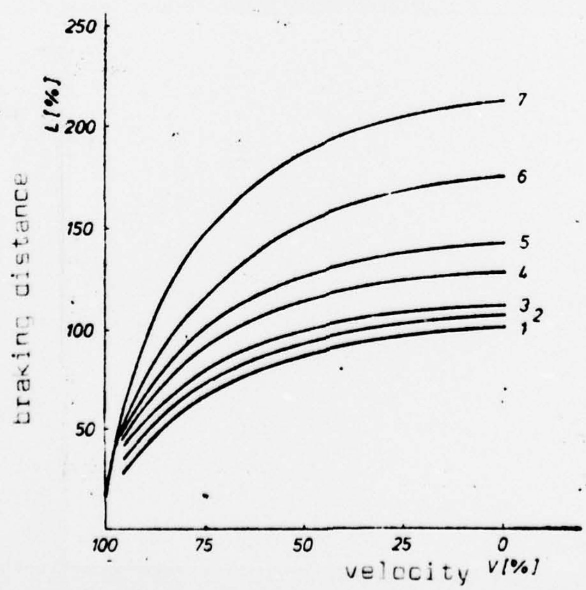

Fig. 11. Dependence of the braking distance vs. aircraft velocity for different antiskid systems: 1-motion at μ_{max_s}, 2-self adjusting relay, 3-self adjusting proportional, 4-W, 5-$\Delta\omega$, 6-s, 7-wheels blocked.

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